Multi-scale viscoplastic behaviour of Halite: In-situ SEM full field measurements, a micro-mechanical approach

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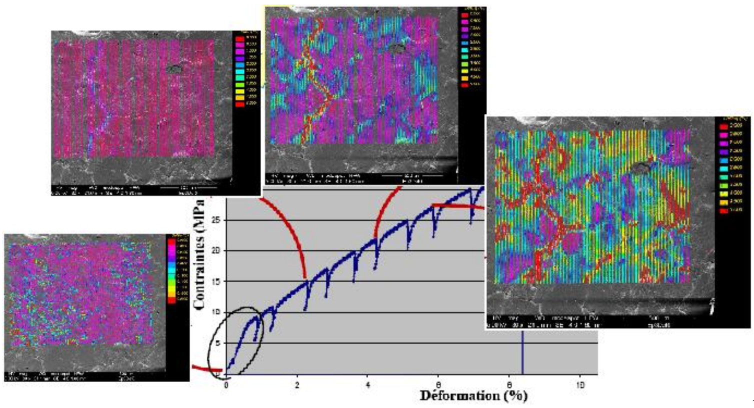
Halite geological formations are already extensively used for underground storage of hydrocarbons. For example, the entire USA federal reserve of petrol resides in deep (500 – 1000 m) artificial salt caverns, which are realized by controlled dissolution. In France, many such salt caverns are used for storage of natural gas by GDF. Salt caverns and carries are also intended to become nuclear waste repositories. At this point, salt caverns are also seriously envisaged for the daily storage of energy from renewable, but intermittent sources (photovoltaic, Aeolian), under the form of compressed air.

Halite mechanical behaviour was extensively studied for the purpose of safe geothechnical applications. Halite is a ductile type rock. Its differed (time-dependent) mechanical response dominates by far, and therefore deep salt caverns experience convergence (closure), which may result in catastrophic subsidence of the overlaying geological layers. Hence, a particular attention was drawn to characterize salt single crystal creep properties (active slip systems and critical resolved shear stresses), and the rheology of poly-crystalline salt, at various temperatures, pressures, differential stresses and water contents (Ter Heege et al., 2007). But, most studies were concerned with macroscopically derived flow laws, corresponding to rather high differential stresses (as compared with those experienced on site), where crystal slip plasticity (CSP) dominates. But, many studies have also shown that halite is very sensitive to solution-precipitation creep (SPC) mechanisms, which may result in solution transfer accommodated grain boundary sliding (GBS). Conversely, some recent studies report that halite is able to flow at ambient conditions, and under very small loads, with strain rates much faster (four orders of magnitude) than those extrapolated from high stress experiments (Bérest et al., 2005). Though, the specific creep micro-mechanisms were not identified, Bérest et al. (2005) invoked possible SPC. Additionally, the effects on long term behaviour of cyclic loading (fatigue) are still poorly known. It is therefore still questionable weather it is really possible to safely extrapolate the laboratory data to the long term envisaged geotechnical applications. To answer we need i) additional experimental work in order to up date the deformation mechanism maps on the basis of better identified micro-physical mechanisms and quantification of their respective activity; and ii) numerical modelling at the scales of the material, and of the underground storage structures, in respect with the appropriated thermo-hygro-mechaniclal loadings.

In the present work, we present our preliminary investigation of viscoplastic global and local responses of synthetic fine grained (50 – 500 μm) halite by the means of full field measurements (FFM) of local strain by digital image correlation (DIC) during simple compression in-situ SEM (Doumalain et al., 2003). Figure 1 shows a typical loading curve obtained incrementally at the constant strain rate of c.a. $5x10^{-5}$ s^{-1}. CSP evidenced by the development of slip lines on the free grain surfaces, and characterized by quasi-linear strain hardening, dominates the overall response up to several % of strain (microfracturing did not appear before 8 % strain). Yet, at the scale of the microstructure, the development of viscoplastic strain is heterogeneous, as shown by the strain maps obtained by DIC and corresponding to four incremental stages of the loading sequence. The heterogeneity of the strain field relates to the loading boundary conditions and to the local microstructure, such crystal size and orientation (which is characterized by electron back scattering diffraction, EBSD). Such micromechanical approach aims to provide the basis for the development of FE (finite element) computational CSP of polycrystalline halite.


a



b

Figure 1: Preliminary uniaxial loading tests in-situ SEM (a) of synthetic halite with heterogeneous microstructure, and preliminary FFM-DIC measurements. The material is tested at constant displacement rate and shows a quasi-linear work hardening. The development of the equivalent (Von Mises) strain field is shown at four stages of the loading.

Literature

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